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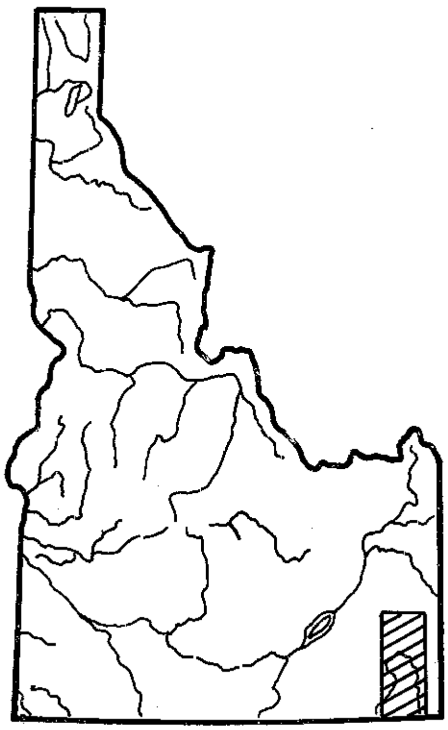

IDAHO DEPARTMENT OF WATER ADMINISTRATION

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AN ESTIMATE OF LEAKAGE FROM BLACKFOOT RESERVOIR TO BEAR RIVER BASIN, SOUTHEASTERN IDAHO

by

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Prepared by the United States Geological Survey

in cooperation with

Idaho Department of Water Administration

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AN ESTIMATE OF LEAKAGE FROM BLACKFOOT RESERVOIR TO BEAR RIVER BASIN, SOUTHEASTERN IDAHO

by

N. P. Dion

ABSTRACT

Blackfoot Reservoir in southeastern Idaho is situated almost entirely on a thick sequence of fractured basalt. Water-level contours indicate that water is leaking out of the reservoir (Snake River drainage) into the Soda Creek basin (Bear River drainage).

The basalt of the Blackfoot Lava Field varies locally from a very productive aquifer to only a fair aquifer. Yields of 200 to 3,500 gallons per minute and specific capacities of 3 to 3,500 gallons per minute per foot of drawdown have been reported. Numerous carbonated springs occur in the headwaters and along the course of Soda Creek, and extensive deposits of tufa occur in the Soda Creek drainage. It is probable that the tufa has affected the permeability of the basalt, at least locally where the springs now discharge or have discharged in the past.

Modified hydrologic-budget analyses that compared actual and expected yields of subbasins indicated that: (1) the amount of leakage from the Blackfoot River basin is about 10 cubic feet per second; (2) the excess yield of Soda Creek is about 52 cubic feet per second and (3) the excess yield between gaging stations on Bear River upstream and downstream from the mouth of Soda Creek is 49 cubic feet per second. Much of the difference between the estimated leakage from Blackfoot Reservoir and the water yield of Soda Creek and Bear River is the contribution of the numerous carbonated springs in the region.

Raising the stage of the reservoir 9 feet, as proposed, would increase both the hydraulic gradient of the ground water south of Blackfoot Reservoir and leakage from the reservoir to Soda Creek basin by about 60 percent.

INTRODUCTION

Background

Shortly after storage of water began in the Blackfoot Reservoir in 1910, it was reported that leakage from the reservoir had converted the Fivemile Meadows area (fig. 4), which is between the reservoir and the town of Soda Springs, from productive hay land to unproductive marshland. In addition Soda Creek, which drains the Fivemile Meadows area and discharges into the Bear River, reportedly doubled its discharge in a matter of days (Mansfield, 1927, p. 326). Hydrologic investigations since that time have qualitatively supported the existence of leakage from the reservoir. A quantitative estimate, however, has never been made to substantiate the qualitative claims.

Blackfoot Reservoir is situated almost entirely on a sequence of basalt flows. Water-level maps (Armstrong, 1969; Dion, 1969) indicate that at least some leakage from the reservoir moves southward beneath a surface-water drainage divide that separates the Blackfoot River basin (Snake River drainage) from the Bear River basin (Great Basin drainage). This leakage could be considered as water that had its source wholly within the State of Idaho. For Idaho to receive credit for this water in its dealings with the Bear River Compact Commission, a reasonable estimate needs to be made of the volume of water involved in the leakage.

Recently, the U. S. Army Corps of Engineers (1968, and written commun., 1969) proposed modification of Blackfoot Dam and China Hat Dam to allow raising the maximum reservoir level by about 9 feet. The effect of this increase in reservoir stage on the amount of water leaking from the reservoir needs to be determined so that Idaho can be credited its fair share of the water in the Bear River.

The study summarized in this report was started in 1971 by the U. S. Geological Survey in cooperation with the Idaho Department of Water Administration.

Objectives of Report

The objectives of this report are to present the results of a study aimed at estimating as accurately as existing data permits, (1) the amount of water leaking from Blackfoot Reservoir into the Bear River basin under existing conditions, and (2) the effect on this amount of raising the maximum stage of the reservoir by as much as 9 feet.

Location and General Features

The study area (fig. 1) lies partly in the Blackfoot River basin (Snake River drainage) and partly in the Bear River basin (Great Basin drainage) of southeastern Idaho. The area is in the Basin and Range and Middle Rocky Mountain physiographic provinces (Fenneman, 1931).

Several northwest trending mountain ranges occur in study area, including the Bear River, Chesterfield, Blackfoot, Wooley, and Aspen Ranges (fig. 5). Lowland areas include the Blackfoot Lava Field, the valley of the Bear River southwest and southeast of Soda

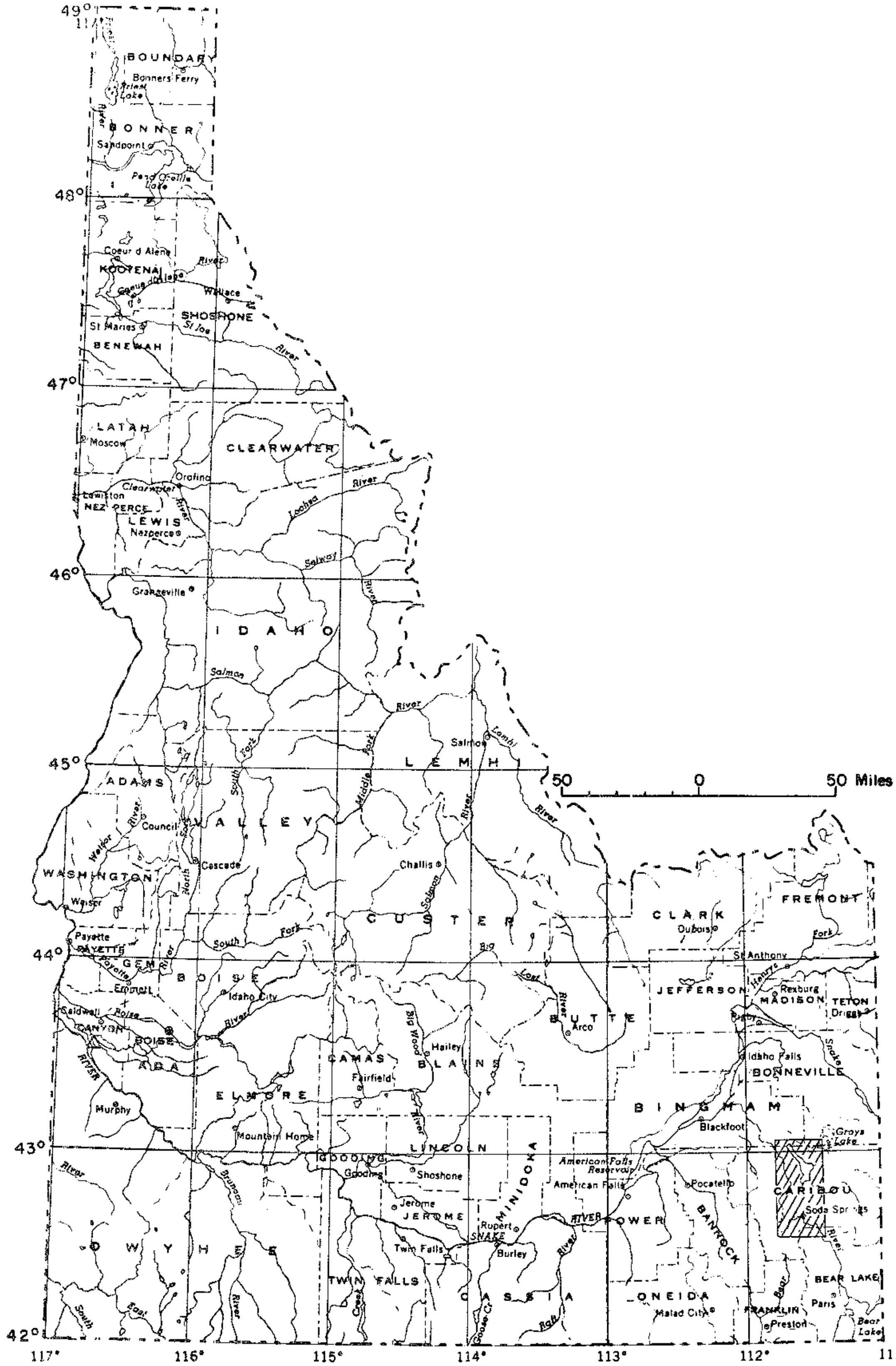

Figure 1. Index map of Idaho showing area covered by this report.

Springs, and the Portneuf Valley-Gem Valley complex. Altitudes in some of the mountain ranges are greater than 8,000 feet. The general landsurface altitude of the lowland areas ranges from about 5,500 feet to about 6,250 feet.

The Blackfoot River heads in the mountain ranges near the Idaho-Wyoming State line and flows northwesterly until it reaches the Snake River Plain near the city of Blackfoot (fig. 1). The river then flows southwesterly to join the Snake River just upstream from American Falls Reservoir. The total drainage area of Blackfoot River is about 1,300 square miles. Only about half this area, however, is tributary to Blackfoot Reservoir.

Blackfoot Reservoir is owned and operated by the U. S. Bureau of Indian Affairs. It is primarily used to store water for irrigation of lands in the Fort Hall Indian Reservation near Blackfoot and Pocatello. The reservoir was originally built in 1910 to store 413,000 acre-feet of water with a surface area of about 18,000 acres at an altitude of 6,124 feet above sea level. A small arm on the south side of the reservoir, now referred to as Dike Lake, was dammed off from the main reservoir by China Hat Dam in 1923 in an effort to reduce leakage from the reservoir. Because the altitude of China Hat Dam is only 6,122 feet, the operating level of Blackfoot Reservoir has been limited to about 6,120.5 feet since China Hat Dam was constructed. Maximum recorded storage was 349,800 acre-feet in 1951 (altitude 6,120.56 feet).

Bear River enters the study area from the southeast, flows around the northern tip of the Bear River Range, and turns abruptly to the south as it enters Gem Valley. Soda Point Reservoir, southwest of Soda Springs, has a surface area of about 1,000 acres at an altitude of about 5,720 feet, and a capacity of about 11,000 acre-feet. The reservoir is used primarily for hydroelectric power production.

Soda Creek, a major tributary of Bear River, heads in the Fivemile Meadows area at an altitude of about 5,980 feet and flows southward to join the river near Soda Springs. The "soda" springs for which the town is named occur in the headwaters and along the course of Soda Creek.

The principal town in the study area is Soda Springs, which had a population of about 2,900 in 1970.

Climate

A National Weather Service weather station has been in continuous operation at or near its present location (sec. 15, T. 8 S., R. 42 E.) at Conda since 1939. Weather at the station (altitude, 6,200 feet) is generally representative of weather throughout the study area.

Conda has a semiarid climate that is characterized by hot summers and cold winters. The mean annual temperature at Conda is 4.4° Celsius (40° Fahrenheit). Mean monthly temperature in January is -8.6° Celsius (16.5° Fahrenheit) and in July it is 17.4° Celsius (63° Fahrenheit).

The mean annual precipitation at Conda is 18.97 inches. July has the lowest (0.78 inch) and June the highest (2.15 inches) mean monthly precipitation (fig. 2). Mean annual snowfall at Conda is about 130 inches.

Average annual lake evaporation is about 35 to 36 inches (Meyers, 1962, pl. 3).

Well-Numbering System

The well-numbering system used by the Geological Survey in Idaho indicates the location of wells within the official rectangular subdivision of the public lands, with reference to the Boise base line and meridian. The first two segments of the number designate the township and range. The third segment gives the section number, followed by three letters and a numeral, which indicate the quarter section, the 40-acre tract, the 10-acre tract, and the serial number of the well within the tract, respectively. Quarter sections are lettered a, b, c, and d in counterclockwise order from the northeast quarter of each section (fig. 3). Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 8S-42E-17cab1 is in the NW¼NE¼SW¼ sec. 17, T. 8 S., R. 42 E., and was the first well inventoried in that tract.

Gaging-Station Numbering System

Each gaging station and partial-record station in Idaho has been assigned a number in downstream order in accordance with the permanent numbering system used by the Geological Survey. Numbers are assigned in a downstream direction along the main stream, and stations on tributaries between main-stream stations are numbered in the order they enter the main stream. A similar order is followed on other ranks of tributaries. The complete 8-digit number, such as 13065500, which is used for the station "Blackfoot River near Henry" includes the part number "13", indicating that the Blackfoot River is in the Snake River basin, plus a 6-digit station number. The part number "10" is used to indicate stations located in the Great Basin.

Previous Investigations

No detailed geologic or hydrologic study of the entire report area has been made although most of the geology and some aspects of the hydrology have been described in parts of other reports. The possibility of leakage from Blackfoot Reservoir to the Soda

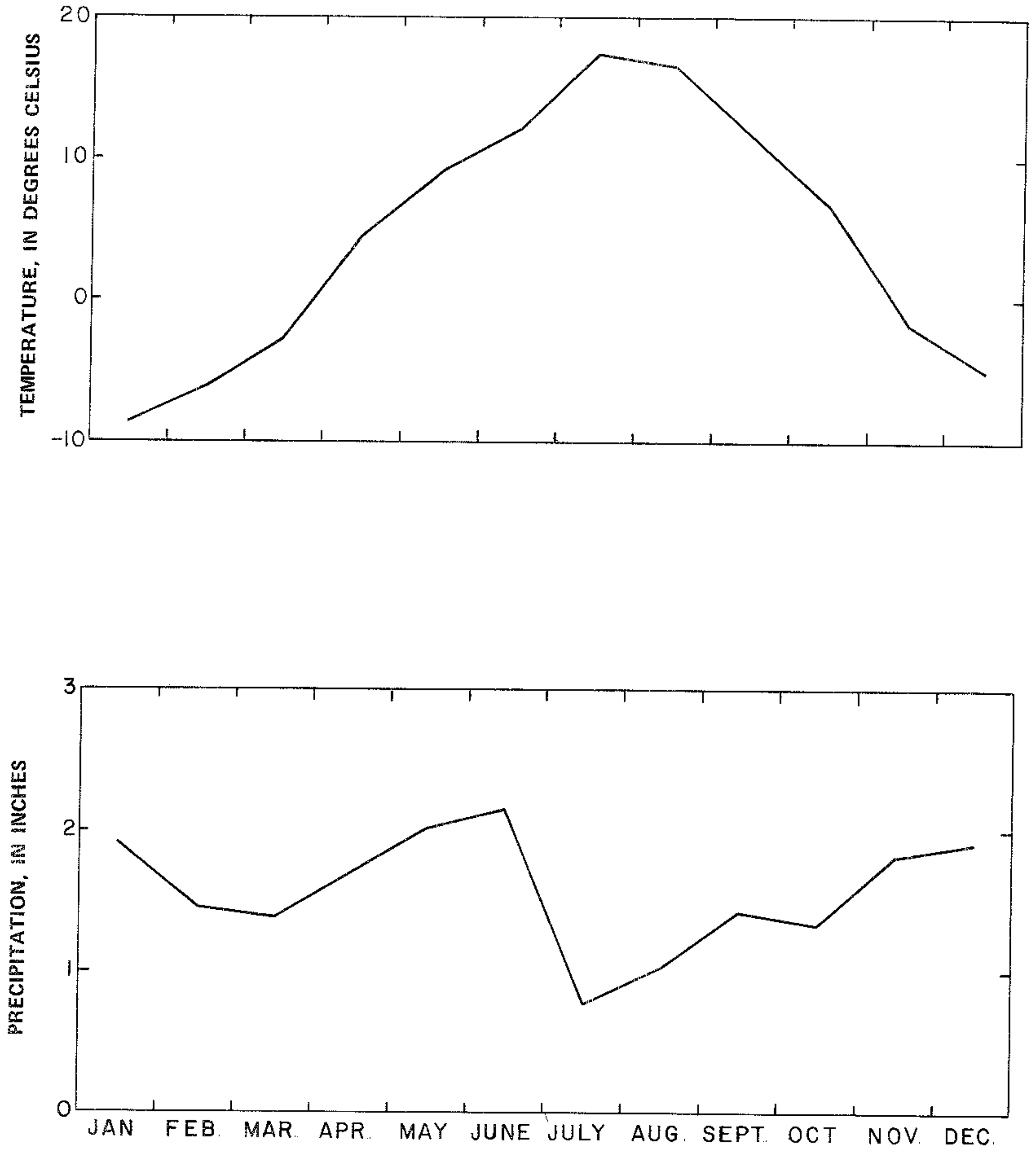

Figure 2. Mean monthly temperature and precipitation at Conda, Idaho (based on data from National Weather Service for 1939-71).

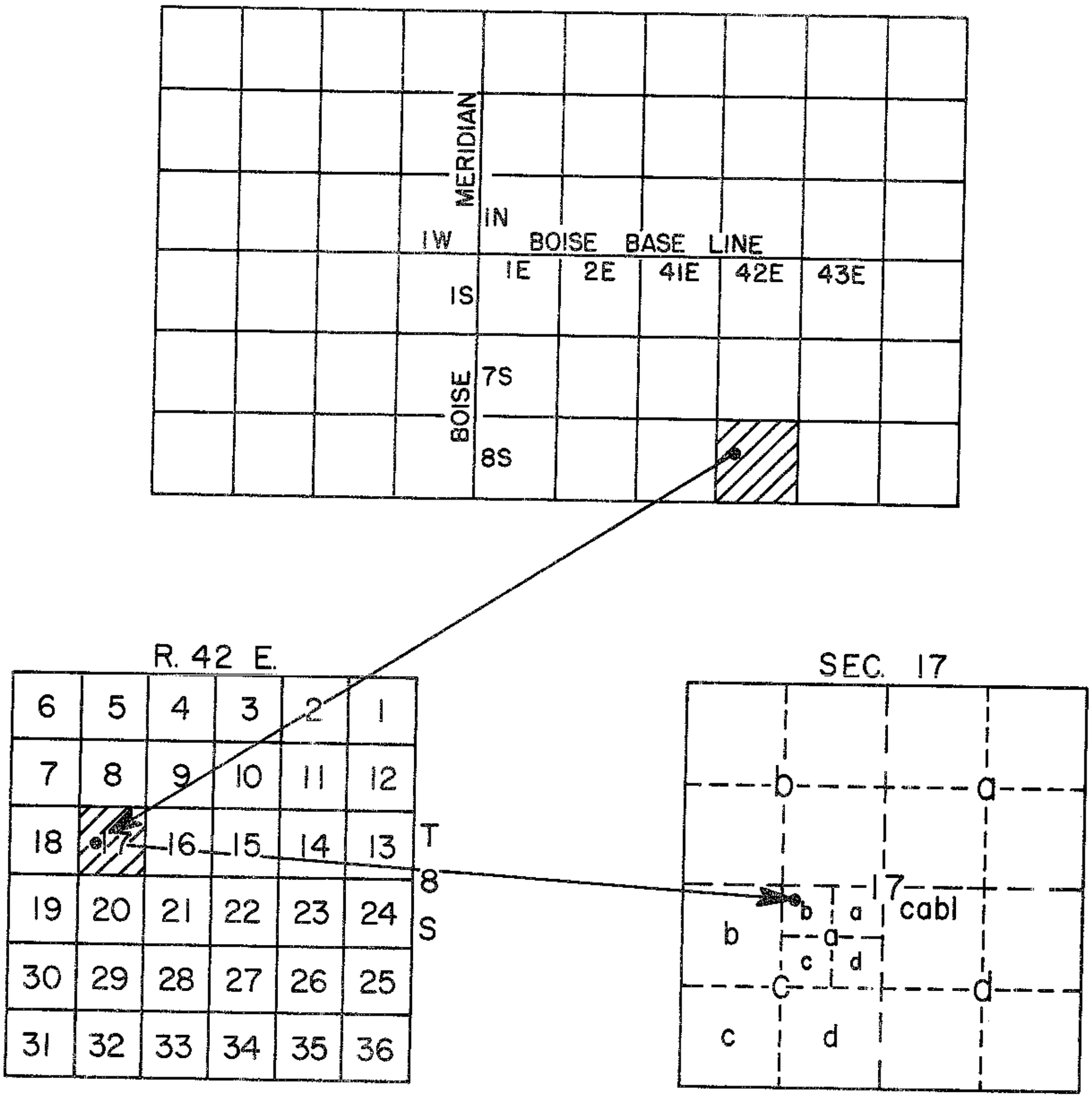

Figure 3. Diagram showing the well-numbering system.
(Using well 8S-24E-17cab1.)

Springs area was first investigated by Umpleby shortly after construction of the reservoir (J. R. Umpleby, unpub. data, 1914). Umpleby found water pouring into basalt crevices on an arm of the reservoir (now Dike Lake) but concluded that the leakage was probably general and not confined to the few crevices he had found. Umpleby presented several other lines of evidence to support the occurrence of leakage, including the formation of Craig Lake, and a lake in the NW¼ sec. 17, T. 7 S., R. 42 E., none of which existed prior to the construction of Blackfoot Reservoir. Although the Umpleby report is unpublished, much of it was used by Mansfield (1927, p. 324-328) in his report on southeastern Idaho. Data obtained by H. T. Stearns and published by Mansfield (1927, p. 314-316 and pl. 3) indicated leakage from the reservoir to the Bear River drainage. Mansfield concurred in Stearn's and Umpleby's conclusions.

Stearns, Crandall, and Steward (1937, p. 227) state: *After the construction of the Blackfoot Reservoir it was found that considerable water leaked away from its south end through a permeable basalt divide and reappeared in the Fivemile Meadows, north of Soda Springs. Soda Springs Creek, a tributary of the Bear River, is fed by springs that derive a large part of their water from the Snake River drainage basin. Thus in the Soda Springs Valley, * * * the ground-water sources of the Snake River and the Bear River are very closely related.*

The earliest geologic mapping was done in the eastern and northern part of the study area by Mansfield (1927) who described the geography, geology, and mineral resources of a part of southeastern Idaho. Geologic mapping of the western part of the study area was completed piecemeal by Mansfield (1929, 1952) and by Oriel (1968). The geology of the Soda Springs guadrangle was later described in more detail by Armstrong (1969). The limits of these geologic studies are shown in figure 4.

H. T. Stearns (unpub. data, no date) described the igneous geology of the Blackfoot Lava Field and the movement of ground water through the basalt. Stearns also described the occurrence and chemistry of the various springs in the Soda Springs region. Dion (1969) made a reconnaissance of the water resources of the entire Bear River basin in Idaho. In that report, Dion stated that the amount of leakage from the Blackfoot River basin into the Bear River basin needed to be determined quantitatively.

A geophysical study of the Soda Springs region by Mabey and Oriel (1970) led those investigators to the conclusion that there is a large mass of inversely magnetized basalt beneath younger, normally magnetized basalt east of Blackfoot Reservoir. In addition, Mabey and Oriel estimated that the basalt in the Blackfoot Lava Field is locally as much as 1,000 feet thick.

GEOLOGIC UNITS AND THEIR WATER–BEARING CHARACTERISTICS

Geologic units ranging in age from pre-Tertiary to Quaternary underlie the report area. The surface distribution of the units shown in figure 4 has been generalized from the work of Mansfield (1927, 1929, 1952), Oriel (1968), and Armstrong (1969). Some of the older geologic units shown in figure 4 also occur at depth below surface outcrops of younger units.

Most wells produce from alluvial deposits and basalt although a few may obtain water from the Salt Lake Formation. The basalt which extends from the Blackfoot Reservoir to Bear River south of Soda Springs is the principal water-bearing formation considered in this report. The basalt occurs as gray to dark-gray vesicular flows, most of which probably originated from local vents. Cinders are relatively common at the vents between Tenmile Pass and Blackfoot Reservoir and drillers' logs show cinders and scoria between some of the flows. Thickness ranges from a thin edge where the basalt laps onto older rocks to several hundred feet as shown by well logs. The maximum thickness of the basalt is not known but Armstrong (1969) and Mabey and Oriel (1970) indicate that the flows may aggregate as much as 1,000 feet in thickness. At many places the basalt is mantled with soil.

In general, the basalt is a good to excellent aquifer. The major water-bearing zones occur at the contacts between flows where open spaces and rubbly zones at the top of one flow were not filled completely by the succeeding flow. Scoriaceous materials and cinders add to the permeability of the formation. A topographic feature of the Blackfoot Lava Field is large scarps or cliffs with a slightly west of north trend between the reservoir and Soda Springs. Armstrong (1969) shows that these cliffs are fault scarps. The fault zones could provide conduits for the movement of water.

Precipitation of minerals from spring water has formed large deposits throughout the Soda Springs basin. These tufa or travertine deposits are porous to spongy white, buff, and yellow calcium carbonates. The deposits contain some iron and manganese and some of the spring water contain enough of the minerals to make the water objectional for domestic use. At some places the tufa is interbedded with the basalt.

It is not known how effectively the tufa deposits have reduced the permeability of the basalt by filling joints and fractures. Spring water moving toward the surface and mixing with "fresh" water in the basalt would be diluted and precipitation of calcium carbonate would be inhibited. On the other hand, spring water moving into unsaturated basalt would tend to precipitate calcium carbonate and fill the joints and fractures.

The descriptions and water-bearing characteristics of the geologic units are summarized in table 1. The geohydrologic section shown in figure 6 illustrates geologic and hydrologic conditions between Blackfoot Reservoir and Soda Springs, an area of prime concern to this study.

GROUND–WATER HYDROLOGY

Ground water occurs in several geologic units in the study area. However, because this study is concerned primarily with water that is moving through the basalt between

TABLE 1

DESCRIPTION AND WATER-BEARING CHARACTERISTICS OF GEOLOGIC UNITS IN THE STUDY AREA.

(Geographic distribution of the units is shown in figure 4.)

PERIOD	ROCK UNIT	DESCRIPTION	WATER-BEARING CHARACTERISTICS
Quaternary	Alluvium (Qal)	Soil, clay, silt, sand, and gravel. Includes well-sorted alluvium deposited in stream channels, alluvial fans at the base of mountain slopes, hillwash and landslide debris. Thickness of unit is 0-100 feet.	Yields small to moderate amounts of water (25-500 gpm) to domestic and stock wells. Locally very thin; part of yield may come from underlying Salt Lake Formation.
	Tufa (Qt)	Porous to spongy white, buff, and yellow calcium carbonate deposited by mineral springs.	Yields small to large amounts of water to springs (as much as 25 cfs). Only a few wells are known to produce from the formation.
Quaternary and Tertiary	Basalt (Qtb)	Porphyritic olivine basalt, cinders, and scoria. Basalt is dark gray, fractured, fissured, and jointed. Some collapse features are evident. Cinders are generally reddish brown. Unit is locally as much as 1,000 feet thick.	Major aquifer in study area. Yields moderate to large amounts of water (500-3,500 gpm) to domestic, stock, irrigation, and industrial wells. Water occurs in fractures and joints in the basalt, in rubbly zones, and in interlying cinder beds.
	Rhyolite (Qtr)	Prominent cones of pumiceous glassy, and perlitic rhyolite. Thickness of unit unknown. Locally younger than the basalt unit.	Unknown as source of water supply, no wells penetrate the unit.
Tertiary	Salt Lake Formation (Tsl)	Fresh-water limestone, tuffaceous sandstone, rhyolitic tuff, and poorly consolidated conglomerate. Generally light colored. Thickness in study area is unknown. Unit probably underlies the basalt unit. Locally faulted.	Highly unpredictable as a source of water supply. Yields varying amounts of water (0-1,500 gpm) to domestic and stock wells.
Pre-Tertiary	Bedrock, undifferentiated (pTu)	Folded and faulted consolidated sedimentary and metamorphic formations, composed of limestone, dolomite, sandstone, quartzite, and shale. Thickness of unit is unknown.	Unknown as source of water supply; very few wells penetrate bedrock in study area. Permeability in the consolidated formations is due largely to secondary openings such as fractures and joints. Solution cavities in limestone give rise to numerous springs.

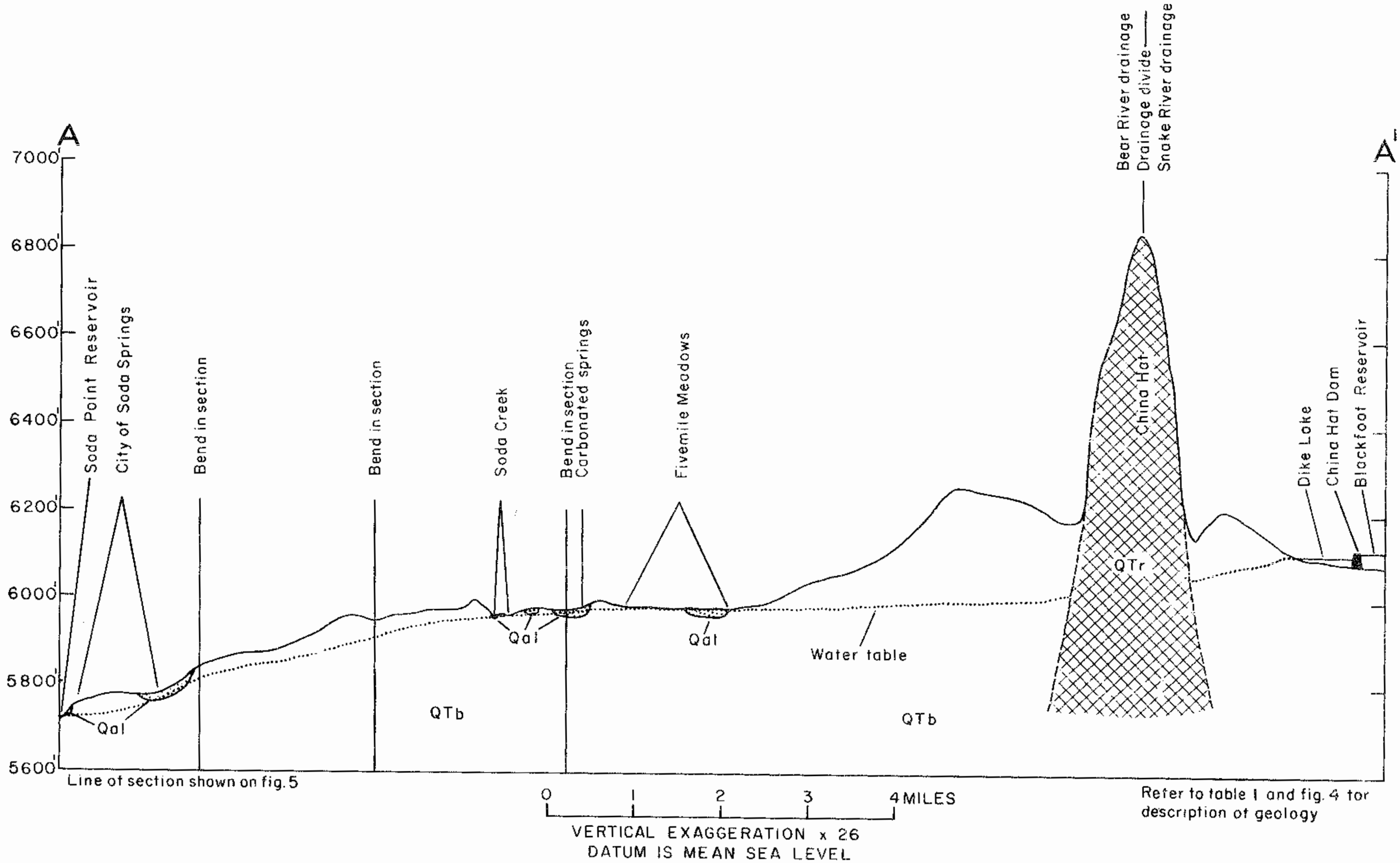

Figure 6. Generalized hydrogeologic section A-A'.

Blackfoot Reservoir and Soda Springs, this section of the report will deal with the hydrology of the basalt in that general vicinity. The author believes that the evidence presented by previous investigators (p. 5) is sufficient to warrant the assumption that water does, in fact, leak out of Blackfoot Reservoir and flow southward toward Soda Springs. The hydrology of the carbonated springs is not known and cannot be discussed in detail.

Ground water occurs in the basalt flows of the study area under water-table conditions. Recharge to the basalt is by leakage from Blackfoot Reservoir and by the downward percolation of snowmelt, precipitation, and irrigation water. Leakage is probably also occurring from the channel of the Blackfoot River upstream from the reservoir for a distance of about 3 miles.

It appears that no significant amount of leakage occurs at Blackfoot Dam. When the gates are closed very little water passes the gage about a mile downstream from the dam and reportedly the channel is essentially dry downstream from the dam for about 4 miles to the mouth of Corral Creek. Also, the U. S. Army Corps of Engineers (written commun., Sept. 1969) made 22 pressure injection tests in 4 drill holes in and near the spillway of the reservoir and found permeability values that ranged from 0.1×10^{-4} to 15×10^{-4} and averaged 5.5×10^{-4} feet per minute. On the basis of these data, there apparently is little water moving out of the reservoir and downstream through the basalt.

The general direction of ground-water movement in the basalt south of the reservoir can be deduced from the water-level map (fig. 5). Movement of the water is downgradient generally at about right angles to the contours. The shape and altitude of the water table south of Blackfoot Reservoir leave almost no doubt to the conclusion that water is leaking out of Blackfoot Reservoir and, possibly, out of the channel of Blackfoot River above the reservoir. The general direction of ground-water flow is to the south past the town of Soda Springs and then to the southwest toward Bear River and the Soda Point Reservoir.

It is possible that some water in the basalt aquifer beneath Blackfoot Lava Field flows into Portneuf Valley through the basalt in Tenmile Pass. The water table in Blackfoot Lava Field is at least 500 feet higher than the water table in Portneuf Valley and the basalt in Tenmile Pass is thick enough to allow passage of water. The entire question of ground-water flow through the pass, however, is open to debate because of a lack of data. The answer to this question would be useful in evaluating the water resources of both the Blackfoot River drainage and the Portneuf River drainage. However, the purpose of this report concerns leakage from the Blackfoot River basin to the Bear River basin. To arrive at a liberal estimate of the leakage, it is assumed that there is no ground-water flow through Tenmile Pass.

A ground-water observation well (8S-42E-17cab1) has been in operation east of Fivemile Meadows since 1967. The hydrograph of this well (fig. 7) indicates that highest water levels occur in the spring and early summer; lowest water levels generally occur in the fall and winter. The dominant factor that controls water levels in the basalt aquifer is

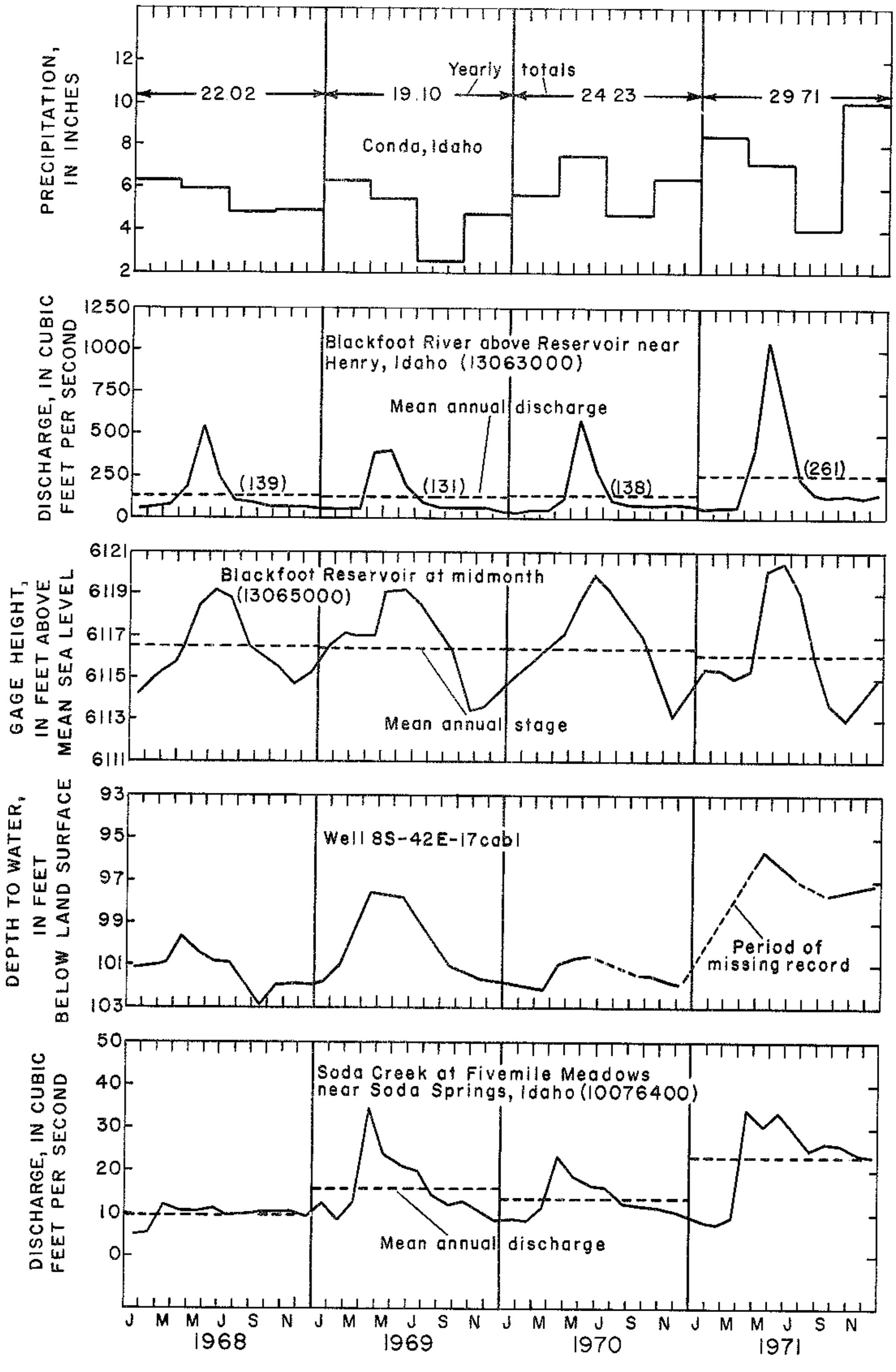

Figure 7. Hydrographs of precipitation, discharge, reservoir stage, and ground-water levels.

unknown at present. Even though the aquifer is recharged in part by leakage from Blackfoot Reservoir, there is no clear correlation between reservoir levels and water levels in the observation well nor between reservoir levels and the discharge of Soda Creek. The spring rise in water levels more nearly coincides with the period of snowmelt. Annual snowfall is on the order of 11 feet and average water content of the snow is on the order of 6.6 inches for the 4-month period December to March (fig. 2).

Yield and specific-capacity values in the basalt aquifer are high in some wells and low in others. According to reports from well drillers and well owners, yields as large as 3,500 gpm (gallons per minute) and specific capacities as large as 3,500 gpm per foot of drawdown are obtainable from the aquifer. On the other hand, some wells yield as little as 300 gpm with 100 feet of drawdown (specific capacity of 3 gpm per foot of drawdown).

Ground water is discharged from the basalt aquifer by several natural and artificial means. Natural discharge is by springs, which feed Soda Creek and other smaller creeks by evapotranspiration in areas where the water table is at or near land surface, and by underflow to the Bear River and to the eastern end of Soda Point Reservoir. Artificial discharge is effected by pumping for various beneficial water uses.

AMOUNT OF LEAKAGE

General

The amount of water presently leaking from Blackfoot Reservoir is estimated in this report using a modified hydrologic-budget analysis in three different locales. The method used involved a comparison of actual and expected yields for parts of the Blackfoot River, Soda Creek, and Bear River basins. In all analyses, actual yields were based on discharge records at current and discontinued Geological Survey stream-gaging stations. Expected surface-water yield rates were estimated from maps prepared by Rosa (1968). Lake evaporation rates were taken from Meyers (1962).

To use the method described above, several assumptions are necessary. These assumptions are: (1) water is, in fact, leaking out of Blackfoot Reservoir and flowing into the Bear River drainage; (2) the entire volume of leakage from the reservoir eventually flows into the Soda Creek basin; (3) the permeability of the basalt through the leakage flows has not changed with a rise in ground-water levels; (4) ground-water underflow beneath all stream-gaging stations has not changed significantly since Blackfoot Reservoir was built; (5) there is no ground-water flow through Tenmile Pass; and (6) the leakage has not increased the flow of the carbonated springs in the Soda Creek basin.

Blackfoot River

This analysis provides an estimate of the difference between actual and expected yields of the Blackfoot River basin on a calendar year basis. The actual yield was considered to be the mean annual discharge at the discontinued stream-gaging station Blackfoot River near Henry (13065500), which is about 0.8 mile below the reservoir. An estimate was then made of the yield that would be expected using available precipitation, evaporation, and water-yield rates for the basin. The difference between the actual and expected yield values represents total leakage from the reservoir.

The data used in this analysis are:

Total area (land and water) above gaging station 13065500 (acres) =	373,000
Land area above gaging station 13065500 (acres) =	361,000
Average water area of Blackfoot Reservoir (acres) (1909-25) =	12,000
Mean annual precipitation on reservoir, based on record at Conda for 1939-71 (feet) =	1.58
Mean annual evaporation from reservoir surface (feet) =	2.92
Mean annual diversions into Blackfoot River basin from Grays Lake for 1909-25 (acre-feet) =	1,000
Mean annual discharge at gaging station 13065500 for 1909-25 (acre-feet) =	186,000
Expected water-yield rate of basin (inches/unit area) (derived from Rosa, 1968) =	0.7

The *expected* yield of the drainage area above gaging station 13065500 for a 1-year period was calculated as follows:

Expected yield of land area = (361,000 acres) (7/12 feet) =	+210,500 acre-feet
Direct precipitation on Blackfoot Reservoir = (12,000 acres) (1.58 feet) =	+19,000 acre-feet
Evaporation from Blackfoot Reservoir = (12,000 acres) (2.92 feet) =	-35,000 acre-feet
Adjustment for precipitation and evaporation for Dike, Craig, North Crater, and South Crater Lakes =	-1,000 acre-feet
Diversions into the basin from Grays Lake =	+1,000 acre-feet
TOTAL =	194,500 acre-feet

The *actual* yield of the drainage area is:

Actual yield = discharge of Blackfoot River near Henry = ... 186,000 acre-feet

The *difference* between the expected and actual yields is:

194,500 acre-feet/year - 186,000 acre-feet/year = ... 8,500 acre-feet

= (rounded) 12 cfs

This represents the amount of water that is calculated to be leaking from Blackfoot Reservoir and entering the Soda Creek basin.

Soda Creek

This analysis was made to determine the excess yield of that part of the Soda Creek basin above gaging station Soda Creek near Soda Springs (10077000). The mean annual discharge at this station is considered to be the actual yield. An estimate was then made of the expected yield of the same drainage area. The difference between the actual and expected yields represents excess yield that originates at least in part in the Blackfoot River basin.

The data used in this analysis are:

Total area above gaging station 10077000 (acres) =	33,300
Mean annual discharge at gaging station 10077000 for 1914-26 (acre-feet) =	44,500
Expected water-yield rate of basin (inches/unit area) (derived from Rosa, 1968) =	5.5

The difference between the actual and expected yields of the drainage area above gaging station 10077000 for a 1-year period was calculated as follows:

Actual yield = discharge of Soda Creek near Soda Springs =	44,500 acre-feet
Expected yield = (33,300 acres) (5.5/12 feet) =	15,300 acre-feet
Difference, or excess yield = 44,500 acre-feet/year - 15,300 acre-feet/year =	29,200 acre-feet/year
	= (rounded) 40 cfs

The 1,800 acres in Fivemile Meadow is occupied by water-loving plants (phreatophytes) and open water. Phreatophytes such as cattail, marsh reed grass, rushes, and wire rush grass evapotranspire 5 to 7.5 feet of water per year (Mower and Nace, 1957, p. 21). Open water evaporation is about 3 feet per year (Meyers, 1962, pl. 3). Assuming the water lost to the atmosphere in the meadows is 5 feet per year, then 9,000 acre-feet or 12 cfs should be added to the water yield of Soda Creek basin for a total actual yield of 52 cfs.

The estimated excess yield of the Soda Creek basin (52 cfs) is larger than the amount of leakage calculated for the Blackfoot River basin (12 cfs). Part of the excess yield of Soda Creek basin, however, is due to the discharge of the numerous carbonated springs near the headwaters of Soda Creek. The source(s) of the carbonated springs may lie outside the drainage area of Soda Creek.

Bear River

This analysis was made as a check of the two previous analyses. The estimated excess yield for the Soda Creek basin should also appear as excess yield between gaging stations on

Bear River upstream and downstream from the mouth of Soda Creek. The gaging stations used in this analysis are Bear River at Soda Springs (10075000) and Bear River at Alexander (10079500). As in the previous analyses, the excess yield was determined as the difference between the actual and expected yields. A diversion for irrigation is made from Soda Creek below the gaging station Soda Creek near Soda Springs (10077000). The water is routed to Portneuf Valley in the Portneuf River drainage basin and does not enter the Bear River. The amount of diversion, therefore, must be added to the flow measured at the gaging station Bear River at Alexander (10079500) to determine the flow that would be expected without the diversion.

The data used in this analysis are:

Mean annual discharge at gaging station 10075000 for 1954-70 (acre-feet) =	382,000
Mean annual discharge at gaging station 10079500 for 1954-70 (acre-feet) =	432,000
Difference in mean annual discharge between gaging stations 10075000 and 10079500 1954-70 (acre-feet) =	50,000
Drainage area between gaging stations 10075000 and 10079500 (acres) =	80,000
Land area between gaging stations (acres) =	79,000
Water area of Soda Point Reservoir (acres) =	1,000
Diversions from Soda Creek to Portneuf River basin (acre-feet) =	11,000
Mean annual precipitation on reservoir, based on record at Conda for 1939-71 (feet) =	1.58
Mean annual evaporation from reservoir surface (feet) =	3.00
Expected water-yield rate of basin (inches/unit area) (derived from Rosa, 1968) =	5.5

The *expected* yield of the drainage area between gaging stations over a 1-year period was calculated as follows:

Expected yield from land area = (79,000 acres) (5.5/12 feet) =	+36,200 acre-feet
Direct precipitation on Soda Point Reservoir = (1,000 acres) (1.58 feet) =	+1,600 acre-feet
Evaporation from Soda Point Reservoir = (1,000 acres) (3.00 feet) =	-3,000 acre-feet
Evapotranspiration from Fivemile Meadow = (5 feet) (1,800 acres) =	-9,000 acre-feet
TOTAL =	25,800 acre-feet

The *actual* yield of the drainage area was calculated as follows:

Mean annual discharge at gaging station 10075000 (acre-feet) =	382,000
Mean annual discharge at gaging station 10079500 (acre-feet) =	432,000
Diversions from Soda Creek to Portneuf River basin (acre-feet) =	11,000
Actual yield = difference in discharge between the two gaging stations = (432,000 + 11,000) - 382,000 =	61,000 acre-feet/year

The *difference* between the actual and expected yields is:

61,000 acre-feet/year - 25,800 acre-feet/year = ... 35,200 acre-feet/year

= (rounded) 49 cfs

The excess yield calculated for the Bear River gaging stations (49 cfs) is close to that calculated for the Soda Creek station (52 cfs) and thus, the excess yield appears in the Bear River between the two stations.

A summary of the three analyses is as follows:

Leakage from Blackfoot Reservoir = ... 12 cfs
Excess yield of Soda Creek basin = ... 52 cfs
Excess yield between Bear River gaging stations = ... 49 cfs

CREDIBILITY OF RESULTS

The reliability of the results obtained in the previous analyses depends in large part on the validity of the assumptions and of the accuracy of the estimates that were made. The values for area, discharge, precipitation, and evaporation are based on actual measurements and are considered to be good. The values for water-yield rates, however, are based on an examination of small-scale maps (Rosa, 1968) and are considered to be, at best, approximate.

Errors made in estimating the expected water-yield rates could lead to serious discrepancies in the results obtained. For instance, if the expected water-yield rate for the Blackfoot River basin had been estimated at 7.5 inches instead of the 7 inches actually used (a difference of only one half inch), the first analysis would have resulted in 32 cfs of leakage, compared to the calculated value of 12 cfs (p. 15). Conversely, if the water yield rate had been estimated at 6.5 inches, the first analysis would have shown that *no* leakage was occurring and that the basin actually had an *excess* yield of 11 cfs.

Ground-water underflow out of the Soda Creek basin above the gage on Soda Creek was not considered in the computation and available data are not useful in estimating the underflow. The ground-water contours indicate that Soda Creek is a ground-water drain and an increase in ground-water recharge, whether from loss from the Blackfoot Reservoir or some other source, would be reflected in increased streamflow. Thus, the volume of underflow probably has changed very little since Blackfoot Reservoir was built.

Although the data are not adequate to accurately compute the amount of leakage from the Blackfoot River basin to the Bear River basin, it is believed that the actual yield of the entire Soda Creek basin is larger than would be expected based on streamflow and precipitation records. The measured tributary inflow to Soda Point Reservoir from the Soda Creek basin averaged 18,000 acre-feet during the period April 15 to September 30 (the normal irrigation season) for the years 1957 to 1971 (Stoker, 1957-71). Measurements made by the Utah Power and Light Company (J. G. Haight, written commun., October 5, 1972) indicate about 35,000 acre-feet inflow to the reservoir occurs during the nonirrigation season. If it is assumed that annual inflow is 53,000 acre-feet plus the 11,000 acre-feet diverted to Gem Valley from the Soda Creek basin, then an average annual water yield of 88 cfs is indicated for this basin. This is equivalent to 11.2 inches of runoff from the 107 square miles of the basin and exceeds the expected yield of 5.5 inches by 204 percent. In addition, there is an unknown amount of ground-water underflow past the gage below Soda Point Reservoir (Dion, 1969, p. 21).

Streamflow from the entire Soda Creek basin (107 square miles) includes three components: runout of precipitation on the basin, discharge of the mineralized (carbonated) springs, and leakage from the Blackfoot River basin. The amount of spring discharge is not known. The discharge of two of the largest has been measured and those that are beneath the water in Soda Point Reservoir have been estimated, but no estimate or measurements have been made of the remainder. The measured and estimated discharge of the carbonated springs may be about 40 cfs. The expected water yield of Soda Creek basin is 31 cfs (107 square miles x 640 acres x 5.5/12 feet = 31,400 acre-feet expected yield -9,000 acre-feet evapotranspiration from Fivemile Meadow = 22,400 acre-feet). Thus, the yield of the carbonated springs is a significant part of the water yield of the basin.

The source of water discharged by the carbonated springs is not known. The nearest adjacent drainage area which is higher than the Soda Creek basin is the upper Blackfoot River basin. One could speculate that precipitation in the upper Blackfoot River basin seeps into the ground, moves through limestone rocks dissolving minerals and picking up carbon dioxide gas, and issuing from springs along the faults which bound the lowland part of the Soda Creek basin. However, data to substantiate this hypothesis are lacking.

In summary, the expected yield of the Soda Creek basin is 31 cfs and the measured carbonate spring discharge is 40 cfs for a total of 71 cfs. Measured inflow to Soda Point Reservoir and water diverted to Gem Valley is 88 cfs. The difference of 17 cfs is about the same order of magnitude as the 12 cfs estimated for the loss from the Blackfoot Reservoir if the unknown amount of underflow past the gage at Alexander is not considered.

This study, as in previous studies, indicates that leakage from the Blackfoot Reservoir to the Soda Creek basin does occur, but an accurate estimate of the amount of leakage cannot be determined from the available data. The data and calculations do indicate, however, that the leakage to Soda Creek is not large but may be on the order of a few tens of cubic feet per second.

INCREASE IN LEAKAGE DUE TO PROPOSED INCREASE IN MAXIMUM RESERVOIR STAGE

Mansfield (1927, p. 324-28) describes the flooding of Fivemile Meadows in 1912. Apparently, the water table was near the surface of the meadows before Blackfoot Reservoir was built. The meadows produced a good crop of hay, shallow-dug wells obtained water from a few feet below the surface, and the headwaters of Soda Creek is near the edge of the meadows. An increase of ground water in storage in the basalt beneath the meadows would raise the water table and waterlog the soil.

As mentioned on page 2, plans have been proposed to raise the maximum stage of Blackfoot Reservoir 9 feet. Modifications to both the Blackfoot and China Hat Dams would allow raising the maximum operating stage from 6,120.5 to 6,126 feet above mean sea level for normal flood control operations and to 6,129 for detention and passage of the probable maximum flood (Corps of Engineers, written commun., 1969). The effects of this increase in stage on the leakage from the reservoir can be estimated by considering the change in hydraulic gradient brought about by the rise and applying the change to the existing conditions. The south and west bank of the reservoir is relatively steep and an increase in reservoir level will not flood a significantly larger area than at present. The width of the flooded area will not increase significantly, and, thus, only the change in hydraulic gradient need be considered.

The amount of water flowing through an aquifer can be expressed by the general equation (Ferris and others, 1962, p. 73):

$$Q\ (\text{gpd}) = TIL$$

where

Q (gpd) = discharge, or flow, in gallons per day;

T = transmissivity of the aquifer, in gallons per day per foot;

I = hydraulic gradient, in feet per mile; and

L = width, in miles, of the cross section through which discharge occurs.

For purposes of this problem, only the hydraulic gradient (I) will be varied; the values of T and L can, therefore, be replaced by a constant. If a second constant is introduced to convert the units of Q from gallons per day to cubic feet per second, the equation becomes

$$Q\ (cfs) = kI$$

where

Q (cfs) = discharge, in cubic feet per second;

k = a constant; and

I = hydraulic gradient, in feet per mile.

Under *existing* hydrologic conditions, the amount of leakage (Q_e) was estimated to be 12 cfs (p. 15). Because at least some of the leakage reappears at ground surface in the Fivemile Meadows area, the hydraulic gradient (I) was calculated for the distance between Blackfoot Reservoir and the 6,100-foot contour. The hydraulic gradient is defined as the ratio of the difference in the average altitude of the reservoir surface and the water-level contour to the distance between the two points. Therefore,

$$I_e = \frac{6{,}117 \text{ feet} - 6{,}100 \text{ feet}}{0.8 \text{ mile}} = \frac{17 \text{ feet}}{0.8 \text{ mile}} = 21 \text{ feet/mile}$$

Under the *proposed* conditions, the stage of Blackfoot Reservoir would be raised a maximum altitude of 6,129 feet. The maximum hydraulic gradient would then be

$$I_p = \frac{6{,}126 \text{ feet} - 6{,}100 \text{ feet}}{0.8 \text{ mile}} = \frac{26 \text{ feet}}{0.8 \text{ mile}} = 32.5 \text{ feet/mile}$$

Since Q is directly proportional to I, Q_p for any increase in reservoir stage is

$$Q_p = Q_e\ (I_p/I_e)$$

For an increase in reservoir stage of 9 feet the amount of leakage would be

$$Q_p = 12(32.5/21) = 19 \text{ cfs}$$

If the same calculations are made for leakage using the altitude of the maximum reservoir stage and the altitude of Fivemile Meadows, the leakage would be 13 cfs. Because it is 8 miles between the reservoir and the meadows it would seem more appropriate to use the first calculation as an indication of potential leakage. The actual volume of leakage, however, will be dependent on the actual rise in stage and the length of time the stage is held at that level. The above calculations should be used only as crude estimates of potential leakage.

A basic assumption in the above calculations is that the permeability (or transmissivity) of the basalt through which the water flows is uniformly distributed. Evidence from the field suggests, however, that there is a wide range in permeability. The basalt in the Blackfoot Lava Field is locally fractured, fissured, and jointed (table 1) and most of the leakage is probably occurring along these localized zones of higher permeability. At other places, the basalt has a low permeability. Four tests by the U. S. Army Corps of Engineers (written commun., 1969) in three core holes at China Hat Dam obtained permeabilities that ranged from 9.5 to 10^{-4} to 22 x 10^{-4} and averaged 14.1 x 10^{-4} feet per minute (14.1 x 10^{-4} cubic feet per square foot per minute = 2.04 feet per day). As the stage of the reservoir is raised, additional zones of high permeability may be encountered and the increase in leakage may be greater than the value calculated above.

SELECTED REFERENCES

Armstrong, F. C., 1969, Geologic map of the Soda Springs quadrangle, southeastern Idaho: U. S. Geol. Survey Misc. Geol. Inv. Map I-557.

Dion, N. P., 1969, Hydrologic reconnaissance of the Bear River basin in southeastern Idaho: Idaho Dept. of Reclamation Water Inf. Bull. no. 13, 66 p.

Fenneman, N. M., 1931, Physiography of Western United States: New York, McGraw-Hill, 534 p.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U. S. Geol. Survey Water-Supply Paper 1536-E, 105 p.

Mabey, D. R., and Oriel, S. S., 1970, Gravity and magnetic anomalies in the Soda Springs region, southeastern Idaho: U. S. Geol. Survey Prof. Paper 646-E, 15 p.

Mansfield, G. R., 1927, Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 409 p.

_____1929, Geography, geology, and mineral resources of the Portneuf quadrangle, Idaho: U. S. Geol. Survey Bull. 803, 110 p.

_____1952, Geography, geology, and mineral resources of the Ammon and Paradise Valley quadrangles, Idaho: U. S. Geol. Survey Prof. Paper 238, 92 p.

Meyers, J. S., 1962, Evaporation from the 17 western states: U. S. Geol. Survey Prof. Paper 272-D, 29 p.

Mower, R. W., and Nace, R. L., 1957, Water consumption by water-loving plants in the Malad Valley, Oneida County, Idaho: U. S. Geol. Survey Water-Supply Paper 1412, 33 p., 2 pl.

Norvitch, R. F., and Larson, A. L., 1970, A reconnaissance of the water resources in the Portneuf River basin, Idaho: Idaho Dept. of Reclamation Water Inf. Bull. no. 16, 58 p.

Oriel, S. S., 1968, Preliminary geologic map of Bancroft quadrangle, Bannock and Caribou Counties, Idaho: U. S. Geol. Survey open-file map.

Rosa, J. M., 1968, Water-yield maps for Idaho: Agricultural Research Service ARS 41-141, 15 p., 20 maps.

Stearns, H. T., Crandall, Lynn, Steward, W. G., 1938, Geology and ground-water resources

SELECTED REFERENCES (CONT'D.)

of the Snake River Plain in southeastern Idaho: U. S. Geol. Survey Water-Supply Paper 774, p. 227.

Stoker, R.D., 1957-71, Watermaster report for District 5, Bear River and Bear Lake, in files of Idaho Dept. of Water Administration.

U. S. Army Corps of Engineers, 1968, Hydrology, Blackfoot Dam and Reservoir, Blackfoot River, Idaho: Design memo. no. 1.

U. S. Geological Survey, 1956, Snake River basin, Part 13 of Compilation of records of surface waters of the United States through September 1950: U. S. Geol. Survey Water-Supply Paper 1317, 566 p.

_____ 1960, The Great Basin, Part 10 of Compilation of records of surface waters of the United States through September 1950: U. S. Geol. Survey Water-Supply Paper 1314, 485 p.

_____ 1963a, The Great Basin, Part 10 of Compilation of records of surface waters of the United States, October 1950 to September 1960: U. S. Geol. Survey Water-Supply Paper 1734, 318 p.

_____ 1963b, Snake River basin, Part 13 of Compilation of records of surface waters of the United States, October 1950 to September 1960: U. S. Geol. Survey Water-Supply Paper 1737, 282 p.

_____ 1970, The Great Basin, Part 10 of Surface-water supply of the United States 1961-65: U. S. Geol. Survey Water-Supply Paper 1927, 978 p.

_____ 1971, Snake River basin, Part 13 of Surface-water supply of the United States 1961-65: U. S. Geol. Survey Water-Supply Paper 1934, 776 p.

_____ Water resources data for Idaho, 1966-70 annual reports: U. S. Geol. Survey.

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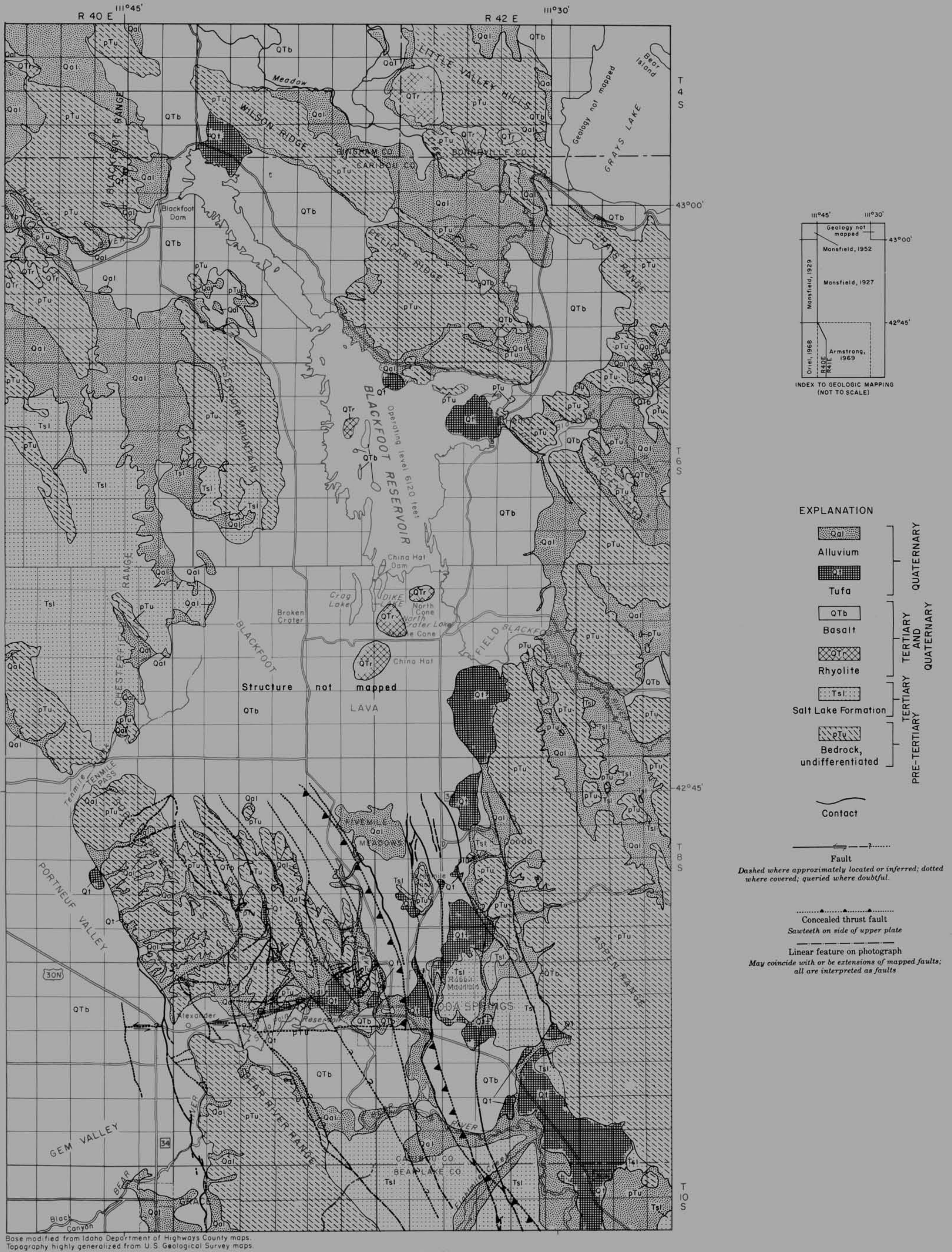

FIGURE 4.--Map of the study area showing generalized geology.

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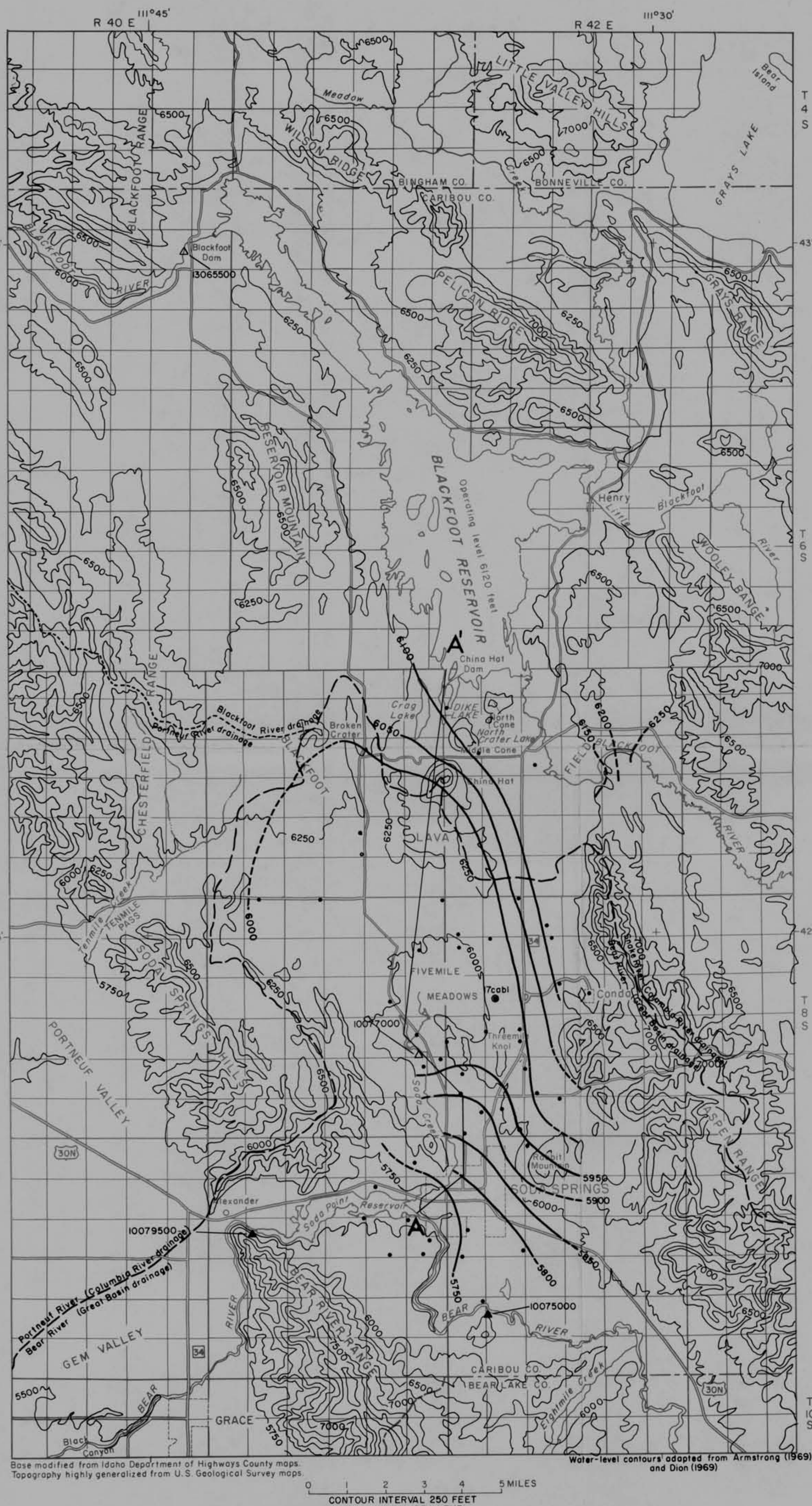

EXPLANATION

5900

Water-level contour
Shows altitude of water level
Dashed where approximately located
Contour interval 50 feet
Datum is mean sea level

A——A'
Line of hydrogeologic section
(shown on fig. 6)

Observation well

17cabl
Observation well and number
(continuous record available)

10075000
Stream-gaging station and number

10077000
Discontinued stream-gaging station
and number

Climatological station

FIGURE 5.-- Altitude of the water table in the basalt aquifer between Blackfoot Reservoir and Soda Springs.